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(54) Title: METHOD AND APPARATUS FOR INCORPORATING ENVIRONMENTAL INFORMATION FOR MOBILE COMMUNICATIONS
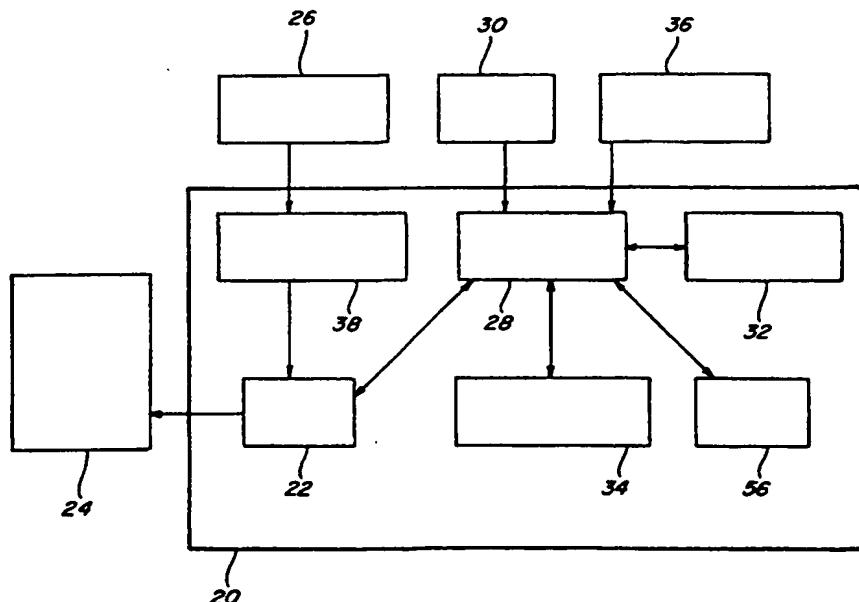
(57) Abstract

An apparatus and method for communicating between a first communication node and a second communication node in an area having a plurality of communications nodes are disclosed which comprises generating a propagation model of signals from selected communication nodes in the area. The communication nodes may be fixed or mobile. The propagation model is based on an environmental map that includes the topography of the terrain and structures in the area. The propagation model is generated at selected intervals to provide updated information for predicting the quality of communication at a location at a future time.

## Description

## METHOD AND APPARATUS FOR INCORPORATING ENVIRONMENTAL INFORMATION FOR MOBILE COMMUNICATIONS

### Technical Field

5        The present invention relates generally to a
method and apparatus for predicting loss of signal
quality in a mobile communications system and, more
particularly, to a method and apparatus for predicting
loss of signal quality in response to knowledge of the
10    environment in which the mobile communications system is
used and also to adapting the routing, network
selection, or other behavior in response to the
prediction to improve the signal quality.

### Background

15    Background

         As mobile machines capable of operating
manually, partially or fully autonomously at work sites
are developed, a large amount of up-to-date information
is required to coordinate particular tasks and to
20    provide adequate time for the machines to plan their
movements. In some situations, multiple pieces of
equipment must work cooperatively with one another and
information regarding the activity and movement of each
machine and other objects in the environment must be
25    communicated. As the work site becomes more complex and
more machines are used, an efficient means for receiving
and transmitting data among the machines is required.
Further, the information that must be communicated is
diverse in nature. For example, the system must support
30    prioritized data, giving precedence to data pertaining
to mission-critical operations. Some of the operations

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may be highly interactive, requiring very low system
latencies.  There is also large variation in bandwidth
requirements, from a few bytes per second to hundreds of
thousands of bytes per second or more.

5          Currently, wireless mobile communications
systems are configured to switch between routes or
networks in response to detection of loss of signal
quality.  For example, cellular systems switch base
stations when the signal level drops below a specified
10   level, such as when a mobile node moves from one base
station area to another.  In some cases the drop in
signal level occurs sufficiently fast that the
connection is lost before hand off to another base
station can be completed.  For example, a communication
15   system for heavy mobile machinery that is operating
partially or fully autonomously cannot afford to lose
valuable data during this fade out period; quality
communications must be maintained at all times.  It is
therefore desirable to have a mobile communication
20   system with means for preventing degradation of
communication signals and loss of information.
In order to make most efficient use of the bandwidth
available, the communication system would ideally have
the capability to choose among several overlapping
25   wireless networks for the networks most suited for a
particular application.  To prevent loss of
communication signals, it is also desired to switch base
stations or networks immediately before the mobile node
moves from one network to another.  This requires the
30   ability to predict handoffs before they are forced and
inform the network when it is discovered that a handoff

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is imminent.  The ability to predict handoffs must be
reliable in a work environment having a large amount of
interference due to complex terrain including hills,
trenches, pits, and tunnels, and where the machinery is
5    spread over large distances. Radio frequency (RF) wave
propagation in regions having irregular terrain and
buildings, such as deep trenches, steep hills, and high
walls, require factors such as the reflection,
diffraction, multi-path, and scattering effects to be
10   taken into account.  The signal strength of the RF
signals can fluctuate greatly with small movements in
such regions.  The reliability of the system must be
balanced with speed, since a wireless network can
typically be made more reliable by adding error checking
15   and correction, at the expense of lower throughput and
higher latency.

In traditional hierarchical data networks,
such as the Internet, routing protocols are tied to the
logical location of the nodes in the network.  When a
20   packet is transmitted, it contains the address of the
destination host computer in its header.  Intermediate
nodes that exist in the path between the source and
destination examine the address of the destination and
make decisions about how to route the packet based upon
25   the network component of this destination address.  This
allows the intermediate nodes to forward the packet to
the network on which the destination host resides
without knowing the exact location of the destination
host.  As the packet travels along the path, the
30   intermediate nodes that are closer to the destination
have information about the exact location of the

environmental map that includes the topography of terrain and structures in the area. The propagation model is generated at selected intervals to provide updated information for predicting the quality of communication at a location at a future time. Additionally, the present invention predicts the future location of a mobile communication node based on the speed and direction of travel of the mobile communication nodes. The previous quality of communication at the predicted location of a communication node is also used. The communication signals are then routed through the network in a manner that provides the desired or best available predicted quality of communication.

Brief Description of Drawings

Fig. 1 is a functional block diagram showing a basic Mobile IP configuration;

Fig. 2 is a functional block diagram showing a basic Mobile IP configuration with packet tunneling;

Fig. 3 is a functional block diagram showing packet routing without Route Optimization;

Fig. 4 is a functional block diagram showing packet routing with Route Optimization;

Fig. 5 is an overview diagram showing an example of coverage of local area and wide area wireless networks;

Fig. 6 is a functional block diagram of the present switching system architecture;

Fig. 7 is a diagram of the state machine that the Model Daemon uses to make switching decisions;

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Fig. 8 is a flowchart showing an example of position-based prediction;

Fig. 9 is an overview diagram of a terrain map;

Fig. 10 is a diagram of the state machine for the present switching system;

Fig. 11 is a view of a graphical user interface for the present switching system; and

Fig. 12 is a view of a work site wherein the present invention may be utilized.


## Best Mode for Carrying Out the Invention
### Overview

The present wireless mobile communication system provides a method and apparatus for communicating between two or more communication nodes in an area having a plurality of communication nodes and one or more communication network technologies. The communication nodes may be mobile or stationary. An intelligent switching system incorporates position information and calculations of RF wave propagation for selected communication networks. At selected time intervals, an environmental map which includes the topography of terrain and structures in the area, as well as the locations and properties of potential sources of electromagnetic interference, is used to create a RF propagation and communications model for signals generated by selected communication nodes and networks in the area. The RF propagation and communications model offers the predicted signal quality at any given location. With these inputs, each

communication node in the present network can predict
where it will be in the future, whether that location
will be reachable via a particular wireless network, and
the quality of the signal at that location.  The network
5   can then prepare to handoff between base stations or
networks having the desired signal quality, thus
minimizing the delay and the overhead incurred.  In
order to support mobile nodes, a communication protocol,
such as the standard Internet protocol known as Mobile
10  IP, is used which allows nodes to change their location
in the network without changing their address.  When a
mobile node moves from one network to another, the home
agent is the only node in the network which keeps track
of the location of the mobile node and routes packets to
15  this location.  The present system also allows direct
peer-to-peer communication.  When two nodes are within
the range of each other's wireless coverage, they can
communicate directly without the aid of any central
router.  When two nodes are beyond the range of each
20  other's wireless coverage, they may be able to
communicate by using other mobile nodes between them to
forward their packets, thus dynamically using these
intermediate nodes as routers and forming an ad hoc
network.  By providing this capability, the present
25  system is able to support a large number of mobile
nodes.  The present system further provides support for
a variety of network traffic types, including data-
intensive file transfers, time-critical emergency data,
real time audio data, constant bandwidth data, and
30  periodic position data.  The type of service required
for the traffic is also considered to meet the special

needs of various communication nodes and facilitating the interaction of different user applications.


## Mobile IP

5          The Mobile IP (Internet Protocol) standard was developed to provide for the mobility of hosts on the Internet. The implementation of Mobile IP, as discussed herein, is based on the IP version 4 (IPv4) protocol standard. Mobile IPv4 allows for the transparent

10    routing of IPv4 packets to mobile nodes in the Internet. There is also a newer version of IP which is known as IP version 6 (IPv6) for which there is also a Mobile IP extension which is known as Mobile IPv6. Both Mobile IPv4 and Mobile IPv6 may be used in the present

15    apparatus.

          In traditional IP routing, if a node has moved to another network, packets destined for it will no longer be deliverable. For a node to be able to communicate on a new network, it must change its IP

20    address. This makes it impossible to maintain connections when the node changes locations. Mobile IP is a routing scheme that does not require a mobile node to change its IP address when it moves. Instead, each mobile node is identified by a single IP address,

25    regardless of its current point of attachment to the network.

          An understanding of Mobile IP requires familiarity with the following concepts:

          Mobile node: A node that moves from one

30    network to another. The mobile node implements Mobile IP in order to maintain communication with other nodes.

Correspondent node: A node with which a mobile node is communicating. A correspondent node could be either a stationary node or another mobile node.

5        Home address: The IP address that is assigned to the mobile node and which remains unchanged, regardless of whether the node is attached to the network.

Home network: Each mobile node has a home

10    network. This is the network to which traditional IP routing would deliver packets addressed with its home address when a mobile node is attached to its home network. Traditional IP routing could deliver packets to the mobile node using its home address.

15        Foreign network: Any network other than the mobile node's home network.

Home agent: A Mobile IP agent located on the mobile node's home network. The home agent keeps track of the location of the mobile node and forwards packets

20    to the mobile node when it is away from home.

Foreign agent: A Mobile IP agent located on a foreign network. Foreign agents may help a mobile node register with its home agent and may also help deliver forwarded packets to a mobile node.

25        Care-of address: An IP address on the foreign network to which the home agent forwards packets. The care-of address could be either the IP address of a foreign agent, or a local address obtained on the foreign network. A protocol such as Dynamic Host

30    Configuration Protocol (DHCP) may be used for this. The former type of care-of address is referred to as a

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foreign agent care-of address and the latter type of
care-of address is referred to as a co-located care-of
address.

Packet interception: This is the process by
5   which the home agent receives packets destined for one
of its mobile nodes. This may be implemented in Mobile
IP by the use of "proxy" Address Resolution Protocol
(ARP) at the home agent. With proxy ARP, the home agent
answers address resolution requests for the mobile
10  node's IP address from other nodes on the home network,
giving the home agent's link-layer address as if it were
the mobile node's address. The node requesting the
address then uses the home agent's link-layer address to
deliver packets to the mobile node, allowing the home
15  agent to receive the packets and to forward them to the
current location of the mobile node.

Binding cache: Correspondent nodes may
maintain a cache of care-of addresses for mobile nodes
in order to determine where to send packets destined for
20  a mobile node.

Binding update: A message used to update a
correspondent node's binding cache.

Registration lifetime: The duration for which
a mobile node's registration on a foreign network is
25  valid. It is also the duration for which a binding
update is valid.

Fig. 1 illustrates the terms defined above. M
is a mobile node. Node S is communicating with M, so S
is a correspondent node. R2 is M's home agent. When M
30  moves to the foreign network, R4 serves as its foreign

agent. In this case, R4's address is used as M's care-of address.

Mobile IP offers a set of services to provide nodes with mobility. This section describes each of
5   these services.

Agent Discovery: Home agents and foreign agents may advertise their availability on each link on which they provide services. In addition, a newly connected mobile node can send an explicit solicitation
10  on a link to learn if any prospective agents are present. Foreign agents will respond to a solicitation by advertising their location. Mobile IP agent discovery is implemented as an extension to the ICMP (Internet Control Message Protocol) Router Discovery
15  protocol. The Agent Discovery protocol extends the messages (Router Advertisement and Router Solicitation) used in the Router Discovery protocol. The messages used in Agent Discovery are thus called Agent Advertisement and Agent Solicitation.
20  Registration: When a mobile node is away from home, it informs its home agent of its current location using a process called registration. Depending on its method of attachment, the node will register either directly with its home agent or through a foreign agent
25  that forwards the registration to the home agent. Registrations are valid for a fixed amount of time, or registration lifetime. If the mobile node is using a co-located care-of address, the presence of a foreign agent is not necessary and the mobile node can register
30  directly. When the mobile node returns to its home

network, it "deregisters" with its home agent to stop
packet forwarding.

　　　　　Tunneling:　The service provided by the home
agent to forward packets to the mobile node is called

5　　"tunneling".　When tunneling packets, the home agent
will encapsulate the original packet by placing another
IP header on the front of the existing packet.　This
"outer" IP header has a source address that is the IP
address of the encapsulating host and has a destination

10　address that is the care-of address of the mobile host.
If the care-of address is the foreign agent, the foreign
agent will receive the packet, decapsulate it, and
deliver it locally to the mobile node.　If a co-located
care-of address is used, the mobile node will receive

15　the packet and decapsulate this packet by itself.

　　　　　Fig. 2 illustrates the process of
encapsulation when a foreign agent is used.　During
operation home agent R2 and foreign agent R4 advertise
their presence using agent advertisement messages.

20　Mobile node M is originally connected to its home
network, so it operates without mobility services at
this time.　Mobile node M moves to a foreign network.
When the mobile node detects that it is on a foreign
network (because it receives the advertisements of the

25　foreign agent), it obtains a care-of address.　The care-
of address is obtained from the foreign agent
advertisement message sent by R4.　If no node such as R4
is available to provide foreign agent services, and if
the mobile node has the capability, it may attempt to

30　obtain a co-located care-of address using a service such
as DHCP.

Mobile node M registers its new care-of address with the home agent R2 through exchange of registration request and reply messages. If R4's address is used as the care-of address, the registration

5    request and reply are sent to the foreign agent R4 which then forwards the packets appropriately. If a co-located care-of address is used, a foreign agent is not involved. When the correspondent node sends packets to M, the packets are routed to M's home network. The home

10   agent R2 intercepts those packets and tunnels them to M's care-of address. If R4's address is the care-of address, R4 decapsulates the packets and delivers them to M locally. If a co-located address is used, the tunneled packets would be received and decapsulted by M

15   itself. In the reverse direction, packets sent by M to S are delivered to their destination using traditional IP routing mechanisms, regardless of the location of M.

Security in Mobile IP is essential due to the fact that it concerns the ability to change the routing

20   of packets destined to any host to be delivered to anywhere else in the Internet. Attacks on registration requests or replies could cause packets destined to the mobile node to be undeliverable or delivered to the incorrect destination. For example, another host could

25   attempt to masquerade as a mobile node and convince a home agent to deliver packets to it. Therefore, authentication is performed by the mobile node and the home agent on all registration request and replay messages. To authenticate with its home agent, the

30   mobile node shares a security parameter index (SPI) and a secret key with its home agent. One of several

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available algorithms may be used for authentication, such as keyed Message Digest version 5 (MD5) with a key size of 16 bytes. To prevent replay of any registration messages, time stamps or nonces are used to uniquely
5    identify each registration request and reply.


## Mobile IP With Route Optimization

          Basic Mobile IP allows a mobile node to move away from its home network by providing a home agent to
10   intercept packets destined for the mobile node's home address. In a typical situation, as shown in Fig. 3, the mobile node M, depicted here is away from its home network and is conversing with a correspondent node S, located on the foreign network to which the mobile node
15   is currently connected. When mobile node M sends a packet to correspondent node S, the packet will be routed directly to mobile node M using traditional IP routing. When correspondent node S sends a packet to mobile node M, however, the packet will first be routed
20   back to the mobile node M's home network. The mobile node M's home agent R2 will intercept this packet and tunnel it to the mobile node's current foreign agent R1. When the foreign agent R1 receives the encapsulated packet, it is decapsulated and then sent to mobile node
25   M.
          Alternatively, the packets may be routed more optimally by sending the packets directly to each other over the local network as shown in Fig. 4. Route Optimization for Mobile IP optimizes the path that
30   packets travel from correspondent nodes S to mobile nodes M. Any type of optimization of the routing of

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packets from correspondent nodes S to mobile nodes M
requires the correspondent nodes S to keep information
about the current location of the mobile nodes M.  Each
correspondent node S that supports Route Optimization
must maintain a cache of care-of addresses, called a
binding cache.  When a correspondent node S sends a
packet, it checks its binding cache for an entry
corresponding to the destination address of the packet.
If a matching entry is found, then the correspondent
node S itself will encapsulate the packet with the care-
of address specified in the binding cache entry,
tunneling the packet directly to the care-of address
instead of sending it to the mobile node M's home
network.

        If a binding cache entry is not found, then
the packet is sent using traditional IP routing which,
as before, causes the packet to be sent back to mobile
node M's home network.  When the home agent R2
intercepts the packet, it assumes the source host does
not have a binding cache entry for the mobile node M.
The home agent R2 will respond by sending an
authenticated binding update to the correspondent node S
to inform it of mobile node M's current care-of address
before tunneling the packet to mobile node M's current
location.  The home agent R2 will set the lifetime of
the binding update to the amount of time remaining for
the registration of that particular mobile node M.  When
the original source receives and authenticates the
binding update, it adds the binding update to the
binding cache for future use.  Binding updates expire

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after the amount of time that is specified by home agent
R2.

In order for a correspondent node S to use
Route Optimization, a software process must be operating
5    to receive and process binding updates.  If the host
does not use the Route Optimization software, then
packets are routed in the same way as in basic Mobile
IP.  Because some correspondent nodes S will not have
this Route Optimization software, home agents R2 must
10   have an algorithm to limit the rate at which they send
out binding updates to each correspond host S, since
otherwise, a home agent R2 might flood the network with
binding updates to a correspondent node S that ignores
them.
15

Intelligent Switching System
The present network system incorporates
multiple technologies to offer the best qualities from
each network, including a wide area wireless network
20   that provides low-speed coverage over a site and one or
more local area wireless networks as shown in Fig. 5,
each providing high speed coverage over a portion of the
site. As mobile nodes move through the network, they are
continuously within the range of the wide-area network
25   and will move into and out of areas of local area
coverage.  The network technology to use in a particular
situation is selected based upon the needs of each
specific application.  A single, composite network made
up of sub-networks using different technologies thus
30   provides a total solution.  The flow of data in this
network takes the most efficient route from the source

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to the destination, depending on the characteristics of
the technologies of the particular sub-networks.  For
example, if a high speed local area communication link
is available between two nodes that want to exchange
5    communication, then that communication path could be
used, as opposed to a slower, wide-area link that might
also be available.  If no other means of communication
between two nodes is available, a wide area network
could be available by default.

10   In a preferred embodiment, Mobile IP is used
to switch between networks as described hereinabove.
The Mobile IP scheme has the advantage that it requires
no changes to the routers or non-mobile nodes in the
network.  The protocol, however, does not specify when
15   to change sub-network connections.

The present system provides the basic Mobile
IP protocol with instruction about which network
connection to establish while requiring minimal change
to the standard Mobile IP protocol.  In the present
20   system, no input from a human operator is required since
some mobile nodes may not carry operators and if they
do, the operator should be able to focus attention on
operating the equipment, not on trying to determine if a
network handoff should occur.  Additionally, one of the
25   inputs into the process of deciding when to switch
networks is an estimate of the quality of the wireless
communication signal from a correspondent on the local
area network.  The current levels of signal strength and
noise or interference could be used to predict future
30   values or recorded for later use.  In addition to being
able to estimate this signal quality value, a threshold

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value is established for a particular local area network technology. This value is the minimum satisfactory signal quality value for the hardware and is obtained either directly from the hardware or from the hardware's specifications. Another useful input to the decision process is knowledge of the current locations of the mobile nodes. This type of input may be combined with knowledge of the locations of wireless local area network transmitters to estimate values of signal quality.

In order to provide realistic models of RF propagation, the present system includes a description of the actual terrain surrounding the mobile node. Using the RF propagation model, the switching system attempts to predict when handoffs will be required in order to minimize the time that a mobile node might be disconnected from the network. The switching system predicts a future value of the signal quality for communications on the local area network connection. This signal quality value is then compared to the specified threshold. If the predicted value exceeds the threshold, the switching system tells Mobile IP to attempt to communicate using its local-area network interface; otherwise, the switching system tells Mobile IP to communicate using the wide-area network connection.


## Switching System Architecture

The components of a preferred embodiment of the present system are shown in Fig. 6. Model Core 20 contains a set of components such as Model Daemon 22,

position-based prediction mechanism 28,
environment/terrain map 32, RF propagation and
communications model 34, non-position-based prediction
mechanism 38, and mobility model 56, that provide the
5    central functions of the switching system.  The
switching system has a modular design so that
improvements in the supporting technologies may be
incorporated.  Model Daemon 22 is a state machine that
keeps track of the current state of the mobile node and
10   makes switching decisions based upon this state and
inputs from two other sources which are a position-based
prediction mechanism 28 and a non-position based
prediction mechanism.  Model Daemon 22 also sends
commands to the Mobile IP software 24, the component of
15   Mobile IP that allows mobile nodes to inform their home
agents R2 of their current location.
        Fig. 7 shows the state machine that Model
Daemon 22 uses to make its switching decisions.  When
Model Daemon 22 begins execution, it starts in the WAN
20   state (where "WAN" refers to the network interface that
Mobile IP is commanded to use, in this case, the wide-
area network interface).  The wide area network was
chosen for the initial state for the present system
because of the assumption that the wide area network
25   will always be available.  From this state, a number of
things can happen.  First, if nothing else occurs, Model
Daemon 22 will send an "update" command to the Mobile IP
software on this node.  Update commands are sent
periodically to ensure that the Model Daemon 22 and
30   mobile node M remain synchronized.

The only way for Model Daemon 22 to leave the
WAN state is if Model Daemon 22 decides that the
empirically collected signal strength values (i.e.,
those read directly from the local-area network

5    interface hardware) suggest that a stable connection to
the local area network (LAN) can be made.  In a
preferred embodiment, this occurs when the Model Daemon
22 reads several consecutive values of signal strength
or hardware signal quality input 26 from the LAN

10   hardware that are above the LAN signal strength
threshold.

Once the Model Daemon 22 has entered the LAN
state, it can only leave if one of the prediction
systems described below predict a future value of signal

15   strength that is below the LAN threshold.  If this
occurs, a command to switch to the WAN interface is sent
to the Mobile IP software on this node, and Model Daemon
22 enters the WAN state again.  Model Daemon 22 sends
"update" commands while in the LAN state to insure that

20   the Model Daemon 22 and Mobile IP software remain
synchronized.

The decision to switch from the LAN interface
to the WAN interface is made based upon predicted
information, while the decision to switch from WAN to

25   LAN is made based upon empirically measured data.  This
distinction is made in order to minimize the possibility
that a mobile node could be instructed to use the local
area network interface when that network is not actually
available.  The result of this is that the rules for

30   changing state make it easier to enter the WAN state,

since the wide area network connection is assumed to
always be available.

Another important point is that Model Daemon
22 has no concept of home or foreign.  It only knows

5  about network interfaces.  The decision of whether the
mobile node M should be home or foreign is left up to
the Mobile IP software or routing protocols 24 (Fig. 6)
and is not affected by the presence of the Model Daemon
22.

10           Referring again to Fig. 6, a position-based
prediction mechanism 28 accepts as an input the current
position of the mobile node from position acquisition
system 30, translates this information into coordinates
on the environment/terrain map 32, and predicts the

15  motion of mobile node M to a new point.  The position-
based prediction mechanism 28 also provides the
coordinates as inputs to the RF propagation and
communications model 34 that calculates future signal
strength values at one or more locations at the site

20  using equations for RF wave propagation.

Hardware for reliably acquiring position
information, such as differential global positioning
systems (DGPS), is readily available commercially.  The
present switching system has a default position

25  prediction system such as the environment/terrain update
system 36 that operates correctly even if the position
information is not available.  To this end, the present
system includes the non-position-based prediction
mechanism 38 that keeps track of empirically collected

30  signal strength values and extrapolates a set of data
points to come up with a future value.

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The extrapolation performed by non-position-based prediction mechanism 38 can be as complex as necessary, taking into account many historical values or just a few, and combining them in a polynomial or
5    fitting them to a curve.  An example of a simple implementation includes defining a line using the two most recently collected signal strength values.  A third point is extrapolated along this line, becoming the predicted signal strength value.  A more useful
10   mechanism would be able to predict further in the future than just the next point in time.  To this extent, a more complex model can be used that fits a curve through a series of points, taking into account the past behavior of the system.

15           The position-based prediction mechanism 28 is part of Model Core 20, and uses information from a number of sources including the environment/terrain map 32, position acquisition system 30, the RF propagation and communications model 34, the environment/terrain
20   update system 36, and the mobility model 56 to provide a predicted value of the future signal strength to Model Daemon 22.  Fig. 8 shows a flowchart of the decision process for predicting a signal strength value.  When the position-based prediction mechanism 28 is invoked at
25   block 40, it first attempts to collect input on the current state of the mobile node.  The current strength of local area network communication is acquired from Model Daemon 22, which previously read the data from the local area network hardware.  The current position of
30   the mobile node is gathered from whatever position system is available as shown at block 42.  Once these

inputs have been collected, the present system checks to
see if the environment/terrain map 32 for the current
location of the mobile node is available at block 44.
If no environment/terrain map 32 is available for this
5    point, a return error is generated at block 46 and the
position-based prediction mechanism 28 cannot be used.
Model Daemon 22 will default to using the value from the
non-position-based prediction mechanism 38.

     If the environment/terrain map 32 for this
10   point is available, then the present switching system
attempts to predict a future position of the mobile node
at block 48.  The future position of the mobile node is
resolved to a specific entry in the environment/terrain
map 32.  The data stored in that location, specifically
15   the historical signal strength value and the time it was
collected, is retrieved.  Once the historical value has
been retrieved, the system stores the current signal
strength value along with the current collection time in
the environment/terrain map 32 at the position specified
20   by the current location.  The amount of time that has
elapsed since the collection time is calculated and
compared against the age threshold associated with the
current terrain map at decision block 50.  If the
elapsed time is less than the threshold, then the
25   historical value is used as the predicted value at block
52. Otherwise, a calculation must be performed using RF
propagation and communications model 34 to predict a
future signal strength value at block 54.  The predicted
signal strength value can then be returned to Model
30   Daemon 22 to be used as input into its threshold
comparisons, as described above.

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Model Daemon 22 can learn about its
environment from places that it has been to before by
using the historical signal strength values. When a
mobile node is using its local area network connection,
5    it can record a collection of signal strength values as
historical values in its environment/terrain map 32. If
the mobile node leaves the area to perform a task, and
returns at a later time to roughly the same place that
it occupied previously, it could use the historical
10   signal strength value as the predicted signal strength
value, making the RF propagation calculations
unnecessary.

The historical values may be aged in
situations where the terrain in some areas of local area
15   network coverage change faster than other areas. The
model allows each area of local area network coverage to
have its own age threshold. For purposes of example
only, the terrain near a site operations center is
likely to be fairly static, since operations typically
20   do not take place near the site operations center. If
this is the case, the age threshold for the site
operations center can be relatively long, such as a week
or so. The age threshold of a work area might only be
valid for a relatively short period of time where the
25   terrain changes more rapidly. If a mobile node returns
to a location that it has been to within the limit of
time set by the age threshold, then Model Daemon 22 can
use the historical value as the predicted value.
Otherwise, Model Daemon 22 must calculate an entirely
30   new value. A more complicated aging system could be
devised which would slowly age the historical values in

the manner of a half-life, possibly combining them in a
weighted polynomial with a value predicted by the RF
propagation and communications model 34.

In a preferred embodiment of the present
5    system, the position acquisition system 30 is a
differential global positioning system (DGPS) system,
although another technology could be substituted.  The
desirable resolution (size in meters of each grid) of
the environment/terrain map 32 is a parameter for the
10   present switching system.  One constraint on this
resolution is that it cannot be finer than the accuracy
of the DGPS equipment.  Smaller grid resolution also
requires more storage space for the environment/terrain
map 32 and more computationally intensive RF propagation
15   model calculations.  A larger grid size will allow
faster calculations and less storage space, but will
represent the terrain with less accuracy, generally
leading to less accurate RF propagation calculations.
The resolution of the "grid" of the terrain map should
20   not exceed the resolution of the position information.
The position information may be represented in units of
degrees of latitude and longitude, or in Cartesian
coordinates having a reference frame fixed in space.
Additionally, it should be noted that the model is not
25   limited to use on a map with a fixed grid.  For example,
maps having irregular mesh descriptions of the terrain
are possible.

The environment/terrain map 32 can be thought
of as a grid that has been placed on the ground over
30   areas where local area network coverage exists, or where
wide area network coverage exists, or, in general, the

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environment/terrain map 32 could exist for all areas,
regardless of network coverage.  At each square in the
grid is a storage location which holds three values.
The first is an elevation value corresponding to the
5    altitude of the terrain at that point above sea level
(or some other reference point). The second value is a
signal strength value.  As a mobile node traverses the
actual terrain, Model Daemon 22 tracks its position
across the environment/terrain map 32 and records the
10   empirically collected values of signal strength into
these storage locations.  The third value stored is the
time at which the most recent signal strength value was
collected.

        An initial terrain data file or mobility model
15   56 (in Fig. 6) contains the elevation information for
the terrain of the local-area network in question.  The
file also specifies the Cartesian coordinates of the
center of the environment/terrain map 32, as an x and y
offset in the desired units of measurement from a fixed
20   reference location, the "size" of the terrain map in
terms of range and resolution in meters, and the age
threshold, mentioned earlier.  Fig. 9 depicts some of
these concepts.  The fixed reference location 58 is the
origin of the Cartesian coordinate system.  Overlaying
25   an outline 60 representing the range of the local area
network is an imaginary grid 62 representing terrain map
32.  The center of the wireless local area network is
located at the center of the terrain map grid 62, and
the grid extends beyond the edges of the coverage of the
30   wireless local area network as represented by outline
60.  The initial terrain data file 56 containing the

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elevation information for this local area network
coverage region specifies the center of the terrain map
32 with respect to fixed reference point 64. With
knowledge of its current position relative to the fixed
5    reference point 64, a mobile node can determine which,
if any, of its available terrain maps 32 are appropriate
for use at a particular position.

          The environment/terrain update system 36 for
calculating a future position of the mobile node several
10   seconds in the future provides Model Daemon 22 with
sufficient warning to send switch commands before
network connectivity is lost completely. In the present
system, various position prediction methods may be used
ranging from using the two most recently collected
15   positions of the mobile node and projecting the path of
the mobile node along a straight line running through
these two points to more complex position prediction
systems that fit a parametric curve, such as a Bezier
curve, through a series of recently collected positions.
20   A more complicated prediction system could make
intelligent predictions of motion based upon the
surrounding terrain or knowledge of commonly followed
routes through the terrain (i.e., roads) and the dynamic
characteristics of the unit.

25            In the current system, the RF propagation and
communications model 34 produces an estimate of the
signal strength of local area communications that a
mobile node would receive based upon a predicted
position of the mobile node, the position of a
30   transmitter (usually a local area network access point
or base station), the terrain between the two, and the

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radio frequency used by the transmission equipment. A
preferred embodiment of RF propagation and
communications model 34 models the effects of natural
terrain on electromagnetic wave propagation in real-
5    time. This model utilizes a two-dimensional path loss
model based on information stored in the
environment/terrain map 32. The two-dimensional model
treats terrain as if it exists within a vertical plane
between an RF transmitter and receiver. RF
10   transmissions can go over or under the terrain, but they
cannot leave the plane to go around terrain features.
In order to construct the two-dimensional model, a
vertical plane is intersected between the x, y, and z
coordinates of transmitting and receiving antennas in
15   the environment/terrain map 32. Two calculations are
then performed on this slice of terrain. First, a free
space estimate of the RF wave propagation from the
transmitter to the receiver is calculated using the
following equation:

20                    $P_r = P_t G_t G_r \square^2 / ((4\square)^2 d^2 L)$

where:

            $P_t$ = the transmitted power

            $G_t$ = the gain of the transmitting antenna

            $G_r$ = the gain of the receiving antenna

25          $\square$ = transmitted wavelength

            $d$ = the distance between the antennas

            $L$ = a system loss factor


        This calculation estimates the received power
30   of the transmissions as if the two antennas were in a
free space, with no obstructions of any kind. Next, a

plane earth calculation is performed.  In a plane earth
estimate of RF propagation, another path from the
transmitter to the receiver is taken into consideration,
the reflected path from the transmitter to the ground to
5    the receiver, using the following equation:

$$P_r = P_t G_t G_r h_t^2 h_r^2 / d^4$$

where:

   $P_t$ = the transmitted power

10   $G_t$ = the gain of the transmitting antenna

   $G_r$ = the gain of the receiving antenna

   $h_t$ = the transmitter height

   $h_r$ = the receiver height

   $d$  = the distance between the antennas

15        Once both of the calculations have been
performed, the lesser of the two (representing the
"worst case" received power) is used as the basis for
the next steps in the modeling calculations.  Some of
the power of RF waves is carried by secondary waves that
20   do not travel on the direct path from the transmitter to
the receiver.  These secondary waves reach the receiver
after being diffracted by point-sources existing between
the transmitter and receiver and carry an important
component of the total transmitted power.  Even if a
25   direct line of sight exists between the transmitter and
receiver, these secondary waves may still be blocked,
reducing the total received power.  A Fresnel zone
refers to a category of these secondary waves based upon
the path that the waves travel.  Adequate Fresnel zone
30   clearance means that there is no significant loss of
power because enough of these secondary waves are able

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to reach the receiver. Fresnel zone clearance is calculated as known in the art depending on which of the following criteria is met:

           1.    A line of sight exists between the transmitter and the receiver and there is adequate Fresnel zone clearance. In this case, the base value calculated before is used as the received power.

           2.    A line of sight exists between the transmitter and the receiver but there is not adequate Fresnel zone clearance. The received power is reduced further from the base power by the loss of secondary waves.

           3.    No line of sight exists between the transmitter and receiver. In this case, only some of the secondary waves are able to reach the receiver.

           The result of these calculations are then passed back to the position-based prediction mechanism 28. A method for calculating a three-dimensional RF propagation model may be used as an alternative to the two-dimensional model. The three-dimensional model will typically require greater data processing resources. Those skilled in the art will recognize that any other RF propagation model could be used as well as the above described model.

## Quality of Service Characteristics

           The present network is primarily concerned with two main quality of service (QOS) parameters: throughput, which is the average amount of data delivered per time unit, usually measured in bits/second or packets/second, and delay, which is the average

length of time for a packet to travel from source to destination.  The present network makes use of the highest bandwidth path from the source to the destination through the use of Route Optimization and

5   the intelligent switching system.  When a high speed, wireless, local area network link is available, it will typically be used instead of the wide area link.

Fig. 10 shows a state diagram 68 for the present switching system wherein a mobile node can only

10  attach to its home network when it is using its local area network interface.  The present system begins with the Connection Lost state which clears some internal variables, disables the local area network interface, and enables the wide area network interface.  Control

15  then passes to the Purge Routes state, which clears the routing information stored by the mobile node.  In the Acquire state, the mobile node attempts to register with its home agent by sending registration requests on all available network interfaces.  Control is then

20  automatically transferred to the Care-of Wait state, where the mobile node waits for a response from its registration requests.  If the attempts to register fail, the mobile node will re-send the registration requests, remaining in the Care-of Wait state.  If re-

25  sending is not allowed, the mobile node will return to the Acquire state and generate new registration requests.  If the registration request is successful, the mobile node enters the Care-of Registered state, which corresponds to the Mobile IP notion of being

30  attached to a foreign network.  The mobile node can remain in this state indefinitely, as long as re-

registration attempts on the same interface that was used previously are successful. Registration attempts can only be made using an interface that is enabled and the mobile node can then be instructed to communicate

5    with a specific interface. If these registration attempts fail, the mobile node returns to the Connection Lost state, and the process begins again.

In addition to the failed registration attempt, the mobile node may leave the Care-of

10   Registered state if a switch command is received from the Model Daemon 22 instructing the mobile node to switch from its local area network (LAN) interface to its wide-area network (WAN) interface. In this case, the mobile node enters the Connection Lost state. If

15   the switch command is to change from the wide-area network interface to the local area network interface, the system must first enable the local area network interface and disable the wide-area network interface. At this point, the system cannot enter the Connection

20   Lost state, because this would change the enable/disabled state of the network interfaces again. Instead, the Connection Lost state is skipped and the Purge Routes state is entered directly. Then, once in the Acquire state using the local-area network

25   interface, the system will either enter the At Home state (if the mobile node is attached to the home network) or eventually the Care-of Registered state (if the mobile node is attached to a foreign network).

At many different places in the state diagram

30   68 the mobile node attempts to detect if its home agent is present on the directly connected sub-networks. If a

home agent is detected (because the mobile node receives home agent advertisement messages), the mobile node immediately enters the At Home state. Once in the At Home state, the mobile node will remain there until it

5      receives a command to switch to the wide area network interface, at which point it will enter the Connection Lost state.

A graphical user interface (GUI) may be provided with the present system in order to monitor the

10    state of the mobile node, as shown in Fig. 11. The switching system GUI consists of a representation of the terrain map 32 and a display of state information. The terrain map is displayed in a grid having the desired dimensions, with the local area network transmitter

15    defining the center of the local area network for the terrain map designated in black at the center of the grid. The height of the terrain may be indicated by colors on the map or other means such as topological elevation lines. The current coordinates of the mobile

20    node, in this case a service truck, relative to the fixed reference, are displayed to the right of the map, and the mobile node's position is shown by the white square on the map. The GUI also displays information about which interface the mobile node is currently using

25    (the LAN or WAN interface) and about the quality of the DGPS information (ON or OFF). Further information on the GUI shows that the mobile node (i.e., the service truck) is at a work area, with coordinates of (-68, - 248, 0). Further, the mobile node is using its LAN

30    interface and its DGPS equipment is functioning correctly.

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## Wireless Local Area Network

The present system requires a local area network in order to provide mobile nodes with the ability to communicate at high speeds to nearby fixed computers or other nearby mobile nodes. One such local area network is WaveLAN, which is a product developed by Lucent Technologies. The modular architecture of the present system can accommodate any local area network technology desired, however. The bandwidth of the local area network used with the present invention must be high enough to support such traffic as isochronous voice data, and burst, high volume traffic such as file transfer and image data. The local area network must also provide access to signal strength measurements for use in the switching system. This signal strength data is a measure of the received power of packets transmitted by another wireless host. The local area network must also allow peer-to-peer communication.

## Wireless Wide Area Network

Another important piece of the present network architecture is the wireless wide area network technology, as it provides communication coverage throughout the entire area operation and constitutes the default communication path for the different entities of the system. Any wide area network technology used with the present network architecture must provide certain capabilities in order to efficiently support the traffic characteristics of the present network architecture.

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One capability is that the wireless wide area network
should be chosen to provide coverage of the entire work
site.  Preferably, this coverage should not restrict the
network to line-of-sight placement of transmitters.  The
5    network must also provide point-to-multipoint or
broadcast capabilities.  Further, support for packetized
data is necessary in order to carry the IP traffic of
the network.  Additionally, although guaranteeing wide
area coverage often compromises the ability to provide
10   high bandwidth, a fair trade off is recommended since
this feature will highly impact the performance of the
overall system.  An example of a suitable wide area
network is the RFM96 Radio Modems, manufactured by
Pacific Crest Corporation.  The Pacific Crest are
15   configured to transmit with a power of 2 watts, giving
them enough range to completely cover a large area
without line of sight placement of antennas.  Another
alternative for a wide area network is the use of low
earth orbit satellites, which are currently under
20   development.

Use With Ad Hoc Networking

In addition to the use of prediction and the
RF propagation model with Mobile IP, the present
invention can also be used in a similar fashion in ad
25   hoc networks.  An ad hoc network is a collection of
wireless mobile hosts forming a temporary network
without the aid of any established infrastructure or
centralized administration.  In such an environment, it
may be necessary for one mobile host to enlist the air
30   of other hosts in forwarding a packet to its

destination, due to the limited range of each mobile
host's wireless transmissions.


## Industrial Applicability

5      The present invention is applicable in
situations where several entities, such as autonomous or
semi-autonomous machines, and operators must coordinate
actions to accomplish tasks as efficiently as possible.
For example, a single site operations center may direct

10     the effort of the machinery for an entire site,
collecting information about the status of the
machinery, and the status of the task to be
accomplished.  In addition, there is a need for
communication between machines and operators to allow

15     close cooperation between them.  Information must also
be communicated to service and maintenance personnel to
alert them to problems that may slow down or halt
performance of the machinery.  The present invention
accommodates a wide range of different types of messages

20     including alert messages, network management messages to
allow communication between nodes, detailed information
about the location of all machinery and the current
state of the task or tasks being performed, audio
transmissions, diagnostic and service manual

25     information, and image data to allow machines to
cooperate with one another and to aid in the diagnosis
of faults.  The present invention provides the ability
for machines to roam between different wireless network
technologies using the Mobile IP protocol with Route

30     Optimization, peer-to-peer communication, and an
intelligent switching system.

        Fig. 12 shows an example of components that
are included at a work site 70, a service truck 72 for
servicing the machinery at work site 70, and a site
office 74.  In this example, a service technician has
5   the ability to take service laptop 76 from the network
at site office 74 and attach it to the mobile network on
the service truck 72 where it registers with mobile
router 78.  When a mobile node, such as excavator 80
begins operation, it sends a packet containing a status
10  message to service truck 72.  The packet originates from
excavator 80 and is sent over wireless local area
network 82 to router 84 at work site 70.  The work site
router 84 is implemented on a host computer system
having data input/output capability and executing
15  software to handle IP data packets, determine the
destination address, and forward the packet over
wireless wide area network 86 to the default home agent
for excavator 80, which is router 88.  Router 88 at site
office 74 receives the packet, determines its
20  destination address, and forwards the packet to local
area network (LAN) 90.  Before the packet is sent out
over LAN 90, router 88 encapsulates the packet with the
service laptop's 76 care-of address as the destination
address, and forwards the packet over local area network
25  82.

        Home agent router 88 determines the source of
the original packet (the excavator 80) and sends a
binding update to excavator 80, informing it of the
current care-of address of service laptop 76, which is
30  the mobile router's 78 address.  Before the encapsulated
packet can be sent out over the local area network 90 to

the service laptop's 76 foreign agent 78, the home agent router 88 intercepts the packet again. This time, the home agent encapsulates the packet with the mobile router's 78 care-of address as the destination address,

5 and forwards the packet over the wide area network 86. The home agent again determines that the excavator 80 is the original source of the packet and sends a binding update to it, telling it the current care-of address of the mobile router 78. The router 84 at work site 70

10 receives the packet from the wide area network 86 and forwards the packet over wireless local area network 82. The mobile router 78 receives the packet from wireless local area network 82 and removes the first encapsulation. The mobile router 78 attempts to forward

15 this inner packet to the correct location. The destination address of this inner packet is the mobile router's 78 own address, so it instead processes the inner packet itself by removing the inner encapsulation and forwarding the packet to service laptop 78.

20 The service laptop 76 receives the packet and replies to the excavator. The packet is first sent to the mobile router 78, since it is the service laptop's 76 default router. Using the wireless local area network's 82 peer-to-peer communication capabilities,

25 the mobile router 78 forwards the packet directly to excavator 80 using wireless local area network 82.

The excavator 80 receives the packet. Excavator 80 also receives the two binding updates from the home agent 88. The excavator 80 uses the binding

30 updates to add entries to its binding cache. Once the excavator has binding cache entries for the service

laptop 76 and the mobile router 78, it can send packets
using Route Optimization until the binding cache entries
expire. The excavator 80 first checks its binding
cache, then the packet is encapsulated using the service

5  laptop's 76 care-of address as the destination address,
which is the mobile router's 78 address. The excavator
80 again finds an entry in its binding cache, this time
for mobile router 78. The packet is encapsulated a
second time using the mobile router's 78 care-of address

10  as the destination address. The packet is then sent
over the wireless local area network 82. Using the
local area network's 82 peer-to-peer capabilities, the
packet is delivered directly to the mobile router 78.
Mobile router 78 receives the packet using wireless

15  local area network 82 and removes the first
encapsulation. The mobile router 78 attempts to forward
this inner packet to the correct location. The
destination address of this inner packet is the mobile
router's 78 own address, so it instead processes the

20  inner packet itself by removing the inner encapsulation
and forwarding the packet to service laptop 76. Service
laptop 76 receives the packet and replies to the
excavator 89. The packet is first sent to the mobile
router 78, since it is the service laptop's default

25  router. Using the local area network's 82 peer-to-peer
capabilities, the mobile router 78 forwards the packet
directly to excavator 80 using wireless local area
network 82. The excavator 80 receives the packet.

Since the excavator has binding updates for

30  the service laptop 76 and the mobile router 78, the
packets are no longer routed over the wide area network

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86.  This utilizes network resources efficiently and
minimizes the use of the low speed wide area network.
Note that in the foregoing example, the Route
Optimization software on the excavator 80 must perform
5  double encapsulation in order to send packets directly
to the service laptop 76.

       The example discussed above included only one
work site, however, the present invention may be
implemented to cover multiple work sites and multiple
10  machines at each work site.

       Other aspects, objects and advantages of the
present invention can be obtained from a study of the
drawings, the disclosure and the appended claims.

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Claims

1.    A method for communicating between a first
communication node and a second communication node in an
5    area having a plurality of communication nodes, the
method comprising the steps of:
            (a)   generating, at selected time intervals, a
propagation model of signals generated by selected
communication nodes in the area based on an
10    environmental map, the environmental map including the
topography of terrain and structures in the area; and
            (b)   predicting quality of communication at a
location at a future time based on the propagation
model.
15

2.    The method, as set forth in claim 1, further
comprising the step of (c) predicting quality of
communication at a future time based on a predicted
location of the communication nodes as a function of the
20    speed and direction of travel of the communication
nodes.

3.    The method, as set forth in claim 1, further
comprising the step of (d) predicting quality of
25    communication at a location at a future time based on
the previous quality of communication at a predicted
location of a communication node.

4.    The method, as set forth in claim 1, further
30    comprising the step of (e) selecting a means of

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communication having the desired predicted quality of
communication.


5.      The method, as set forth in claim 1, further
comprising the step of (c) predicting quality of
communication at a future time based on a predicted
location of the communication nodes as a function of the
speed and direction of travel of the communication
nodes, and (d) the previous quality of communication at
a predicted location of a communication node.


6.      The method, as set forth in claim 1, further
comprising the steps of (c) predicting quality of
communication at a future time based on a predicted
location of the communication nodes as a function of the
speed and direction of travel of the communication
nodes, and (e) selecting a means of communication having
the desired predicted quality of communication.


7.      The method, as set forth in claim 1, further
comprising the steps of (d) predicting quality of
communication at a future time based on the previous
quality of communication at a predicted location of a
communication node, and (e) selecting a means of
communication having the desired predicted quality of
communication.


8.      A method for communicating between a first
communication node and a second communication node in an
area having a plurality of communication nodes, the
method comprising the steps of:

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      (a)   generating, at selected time intervals, a propagation model of signals generated by selected communication nodes in the area based on an environmental map, the environmental map including the

5    topography of terrain and structures in the area; and

      (b)   predicting quality of communication at a location at a future time based on the propagation model,

      (c)   a predicted location of the communication

10   nodes as a function of the speed and direction of travel of the communication nodes, and

      (d)   the previous quality of communication at a predicted location of a communication node; and

      (e)   selecting a means of communication having

15   the desired predicted quality of communication.


      9.   A method for communicating between a first communication node and a second communication node in an area having a plurality of communication nodes, the

20   method comprising the steps of:

      (a)   generating, at selected time intervals, a propagation model of signals generated by selected communication nodes in the area based on an environmental map, the environmental map including the

25   topography of terrain and structures in the area; and

      (c)   predicting quality of communication at a future time based on a predicted location of the communication nodes as a function of the speed and direction of travel of the communication nodes.

30

10.   The method, as set forth in claim 9, further
comprising the step of (d) predicting quality of
communication at a future time based on the previous
quality of communication at a predicted location of a
5    communication node.


11.   The method, as set forth in claim 9, further
comprising the step of (e) selecting a means of
communication having the desired predicted quality of
10   communication.


12.   The method, as set forth in claim 9, further
comprising the steps of:
          (c)   predicting quality of communication at a
15   future time based on a predicted location of the
communication nodes as a function of the speed and
direction of travel of the communication nodes, and
          (d)   the previous quality of communication at
a predicted location of a communication node; and
20           (e)   selecting a means of communication having
the desired predicted quality of communication.


13.   A method for communicating between a first
communication node and a second communication node in an
25   area having a plurality of communication nodes, the
method comprising the steps of:
          (a)   generating, at selected time intervals, a
propagation model of signals generated by selected
communication nodes in the area based on an
30   environmental map, the environmental map including the
topography of terrain and structures in the area; and

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     (d)   predicting quality of communication at a future time based on the previous quality of communication at a predicted location of a communication node.

5

     14.  The method, as set forth in claim 13, further comprising the step of

     (e)   selecting a means of communication having the desired predicted quality of communication

10     based on the propagation model.

     15.  A method for communicating between a first communication node and a second communication node in an area having a plurality of communication nodes, the

15    method comprising the steps of:

     (a)   generating, at selected time intervals, a propagation model of signals generated by selected communication nodes in the area based on an environmental map, the environmental map including the

20    topography of terrain and structures in the area; and

     (e)   selecting a means of communication having the desired predicted quality of communication.

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16. An apparatus for communicating between a first communication node and a second communication node in an area having a plurality of communication nodes, the apparatus comprising:

5          a data processor operable to continuously calculate a propagation model of signals generated by selected communication nodes in the area based on a continuously updated environmental map, the environmental map including the topography of terrain

10   and structures in the area, and to predict the quality of communication at a location at a future time based on the propagation model.

17. The apparatus, as set forth in claim 16,

15   wherein the data processor is further operable to predict quality of communication at a future time based on a predicted location of the communication nodes as a function of the speed and direction of travel of the communication nodes.

20

18. The apparatus, as set forth in claim 16, wherein the data processor is further operable to predict quality of communication at a location at a future time based on the previous quality of

25   communication at a predicted location of a communication node.

19. The apparatus, as set forth in claim 16, wherein the data processor is further operable to select

30   a means of communication having the desired predicted quality of communication.

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20.    The apparatus, as set forth in claim 16,
wherein the data processor is further operable to
predict quality of communication at a future time based
on a predicted location of the communication nodes as a
function of the speed and direction of travel of the
communication nodes, and the previous quality of
communication at a predicted location of a communication
node.


21.    The apparatus, as set forth in claim 16,
wherein the data processor is further operable to
predict quality of communication at a future time based
on a predicted location of the communication nodes as a
function of the speed and direction of travel of the
communication nodes, and select a means of communication
having the desired predicted quality of communication.


22.    The apparatus, as set forth in claim 16,
wherein the data processor is further operable to
predict quality of communication at a future time based
on the previous quality of communication at a predicted
location of a communication node, and select a means of
communication having the desired predicted quality of
communication.


23.    A method for communicating between a first
communication node and a second communication node in an
area having a plurality of communication nodes, the
method comprising the steps of:
             continuously generating a propagation model of
signals generated by selected communication nodes in the

area based on an environmental map, the environmental
map including the topography of terrain and structures
in the area;

predicting quality of communication at a location
at a future time based on the propagation model, a
predicted location of the communication nodes as a
function of the speed and direction of travel of
communication at a predicted location of a communication
node; and

selecting a path of communication among the
communication nodes having the best available predicted
quality of communication.


24. The method as set forth in claim 23, further
comprising the step of:

(f) modifying a packet of data being
communicated from a first communication node to a second
communication node to indicate the selected path of
communication.


25. The method, as set forth in claim 23, wherein
one communication node is a wide area network, and
another communication node is a local area network.


26. A method for communicating between a first
communication node and a second communication node in an
area having a plurality of communication nodes, the
method comprising the steps of:

continuously calculate a propagation model of
signals generated by selected communication nodes in the
area based on a continuously updated environmental map,

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the environmental map including the topography of
terrain and structures in the area; and

     predicting the quality of communication at a
location at a future time based on the propagation
5    model.


     27.   An apparatus for communicating between a first
communication node and a second communication node in an
area having a plurality of communication nodes, the
10   apparatus comprising a data processor operable to
continuously generate a propagation model of signals
generated by selected communication nodes in the area
based on an environmental map, the environmental map
including the topography of terrain and structures in
15   the area, to predict the quality of communication at a
location at a future time based on the propagation
model, a predicted location of the communication nodes
as a function of the speed and direction of travel of
communication at a predicted location of a communication
20   node, to select a path of communication among the
communication nodes having the best available predicted
quality of communication, and to modify a packet of data
being communicated from a first communication node to a
second communication node to indicate the selected path
25   of communication.
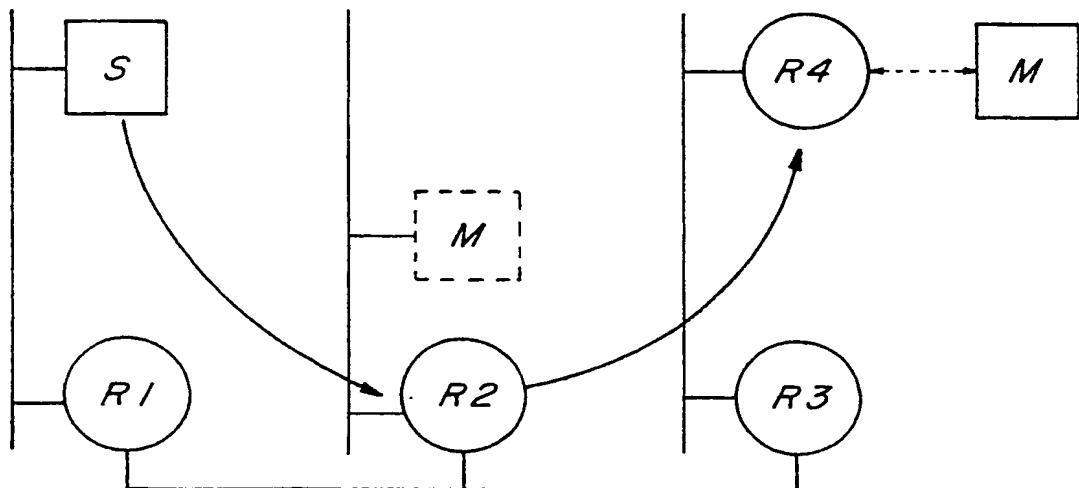
Fig. 1



Fig. 2

Fig. 3

Fig. 4
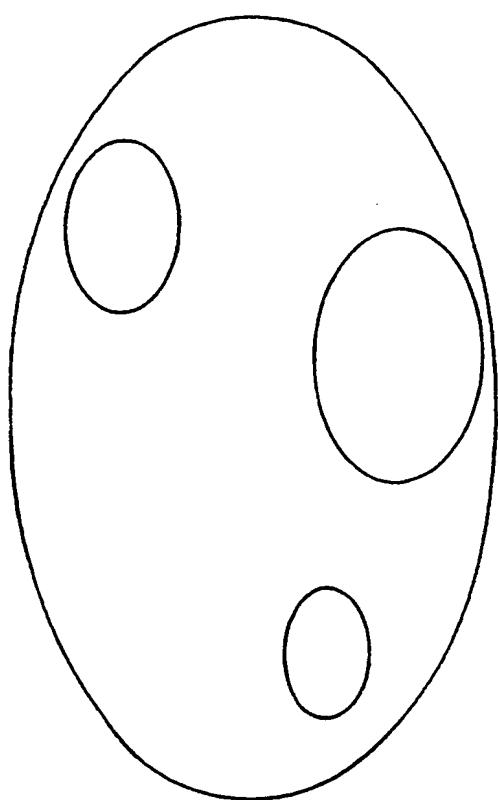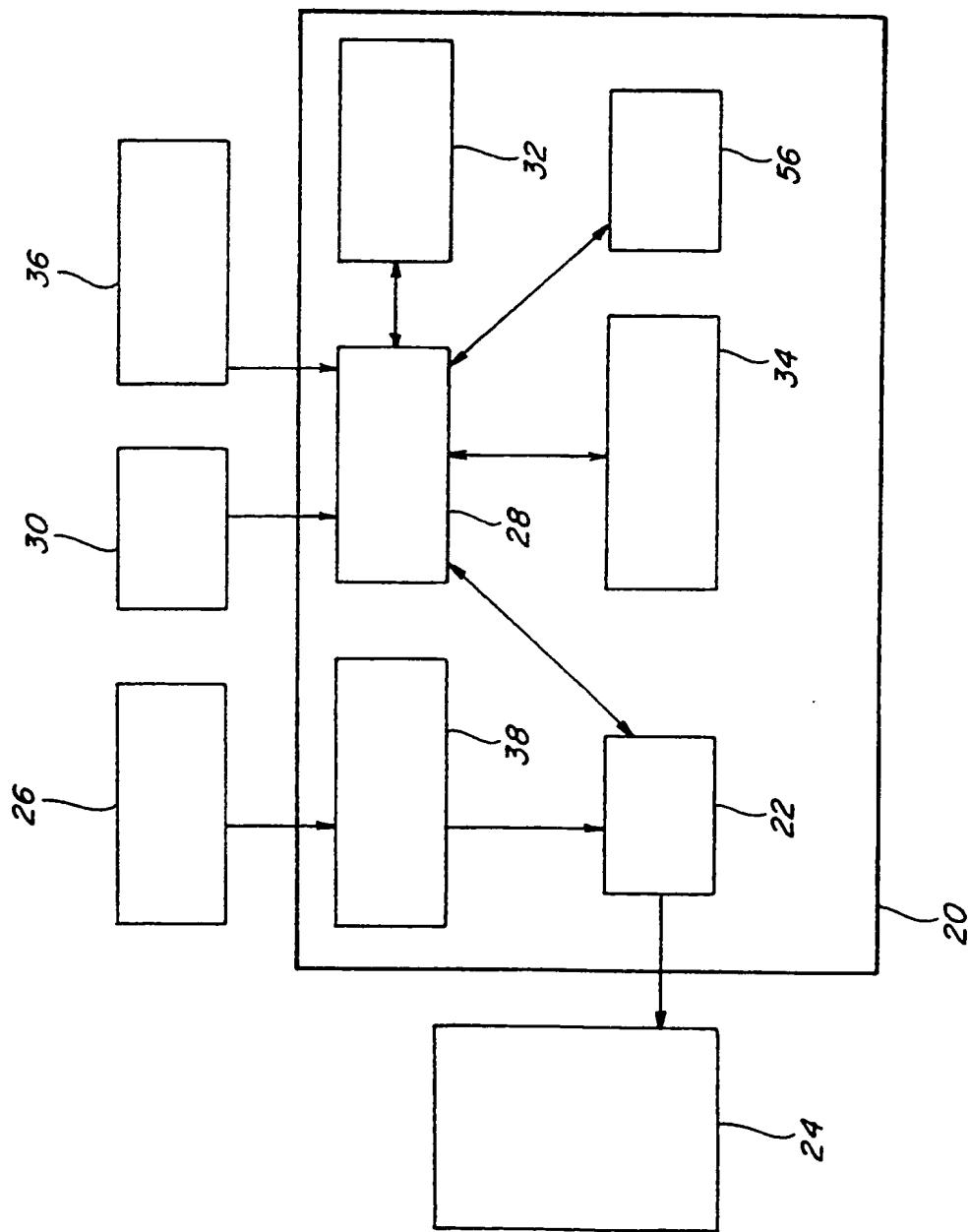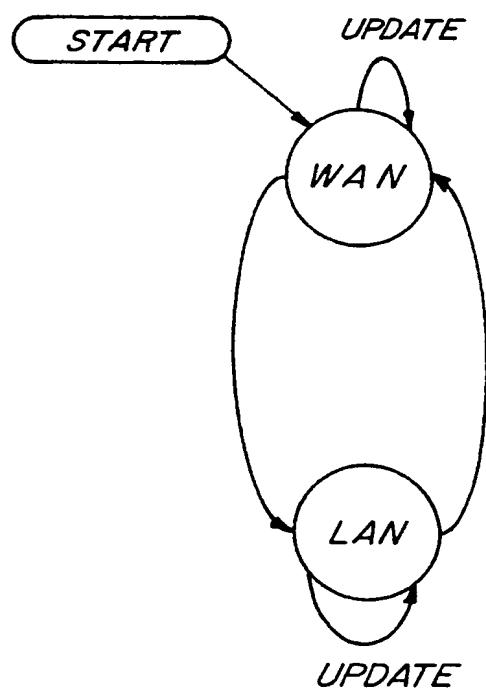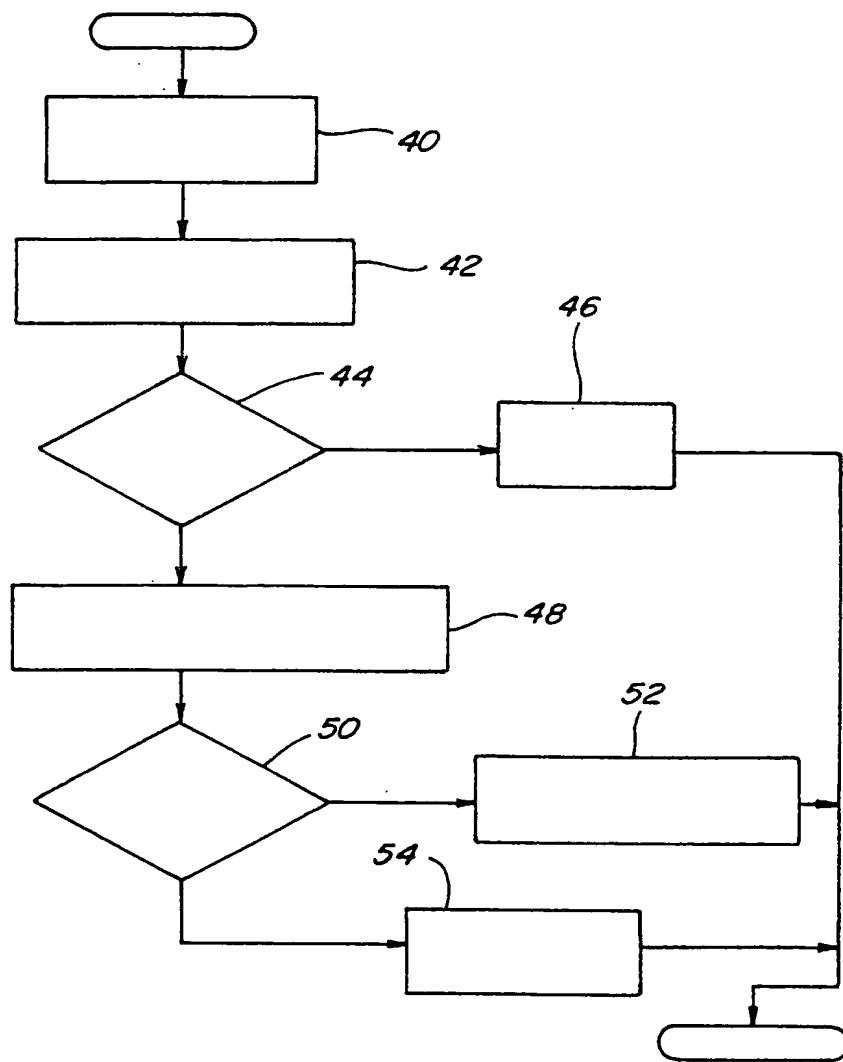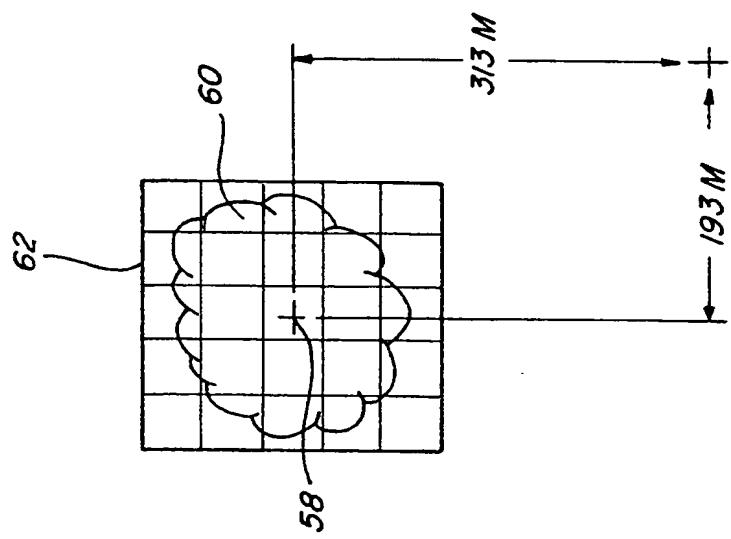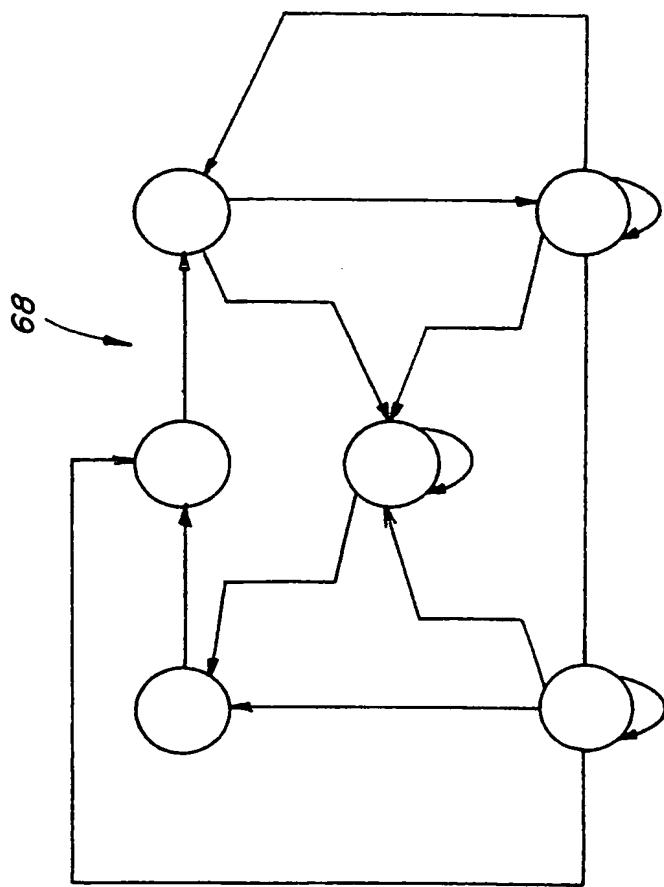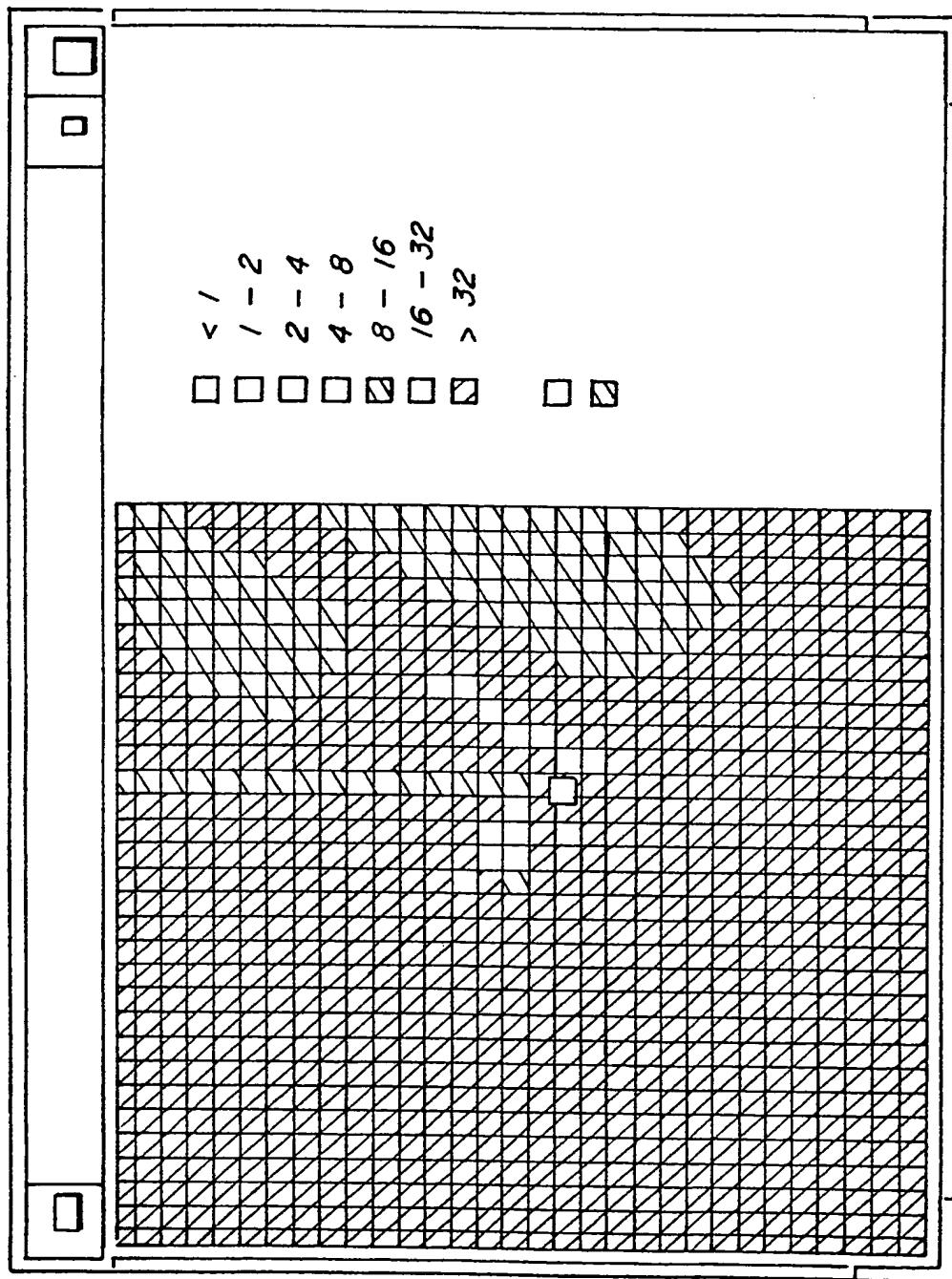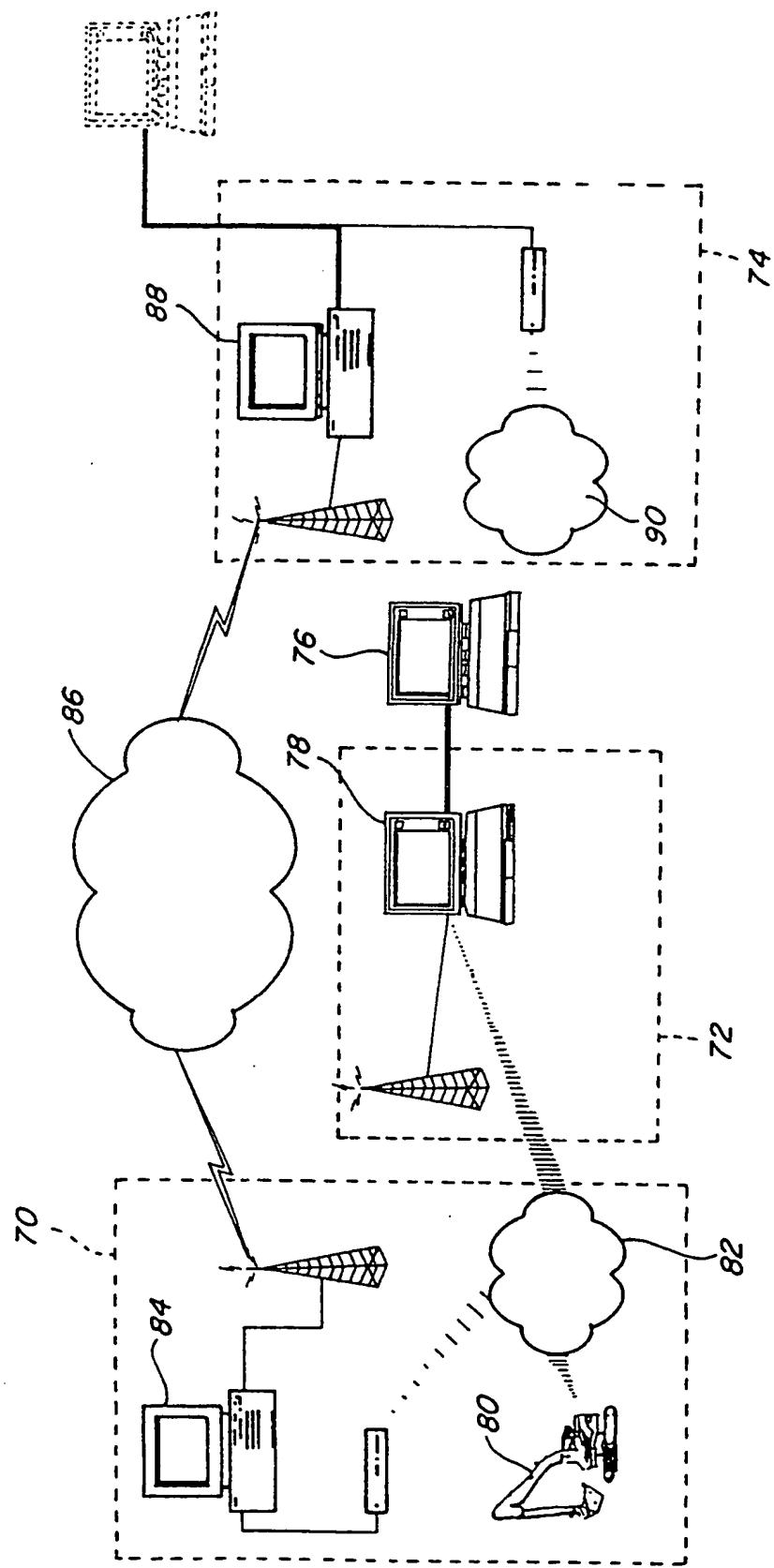
Fig. 5

*Fig. 6*

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*Fig. 7*

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

# INTERNATIONAL SEARCH REPORT

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 6    H04Q7/36

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 6    H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | JUNIUS M: ""INTELLIGENTES" RADIO RESOURCE MANAGEMENT MUSTERERKENNUNG MIT GSM -FUNKMESSDATEN UND ANWENDUNG" ITG-FACHBERICHTE, vol. 124, 27 September 1993 (1993-09-27), pages 487-501, XP002006361 ISSN: 0932-6022 page 490, line 8 -page 494, line 7 page 499, line 18 -page 500, line 24 figures 1-3 | 1-27 |
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[ ] Further documents are listed in the continuation of box C.     [X] Patent family members are listed in annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 11 October 1999 | 15/10/1999 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016 | Heinrich, D |

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